The Terminal Area Simulation System: Providing Solutions to Aviation Weather Problems

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14 July 2004, AirSC Technical talk

OUTLINE

- Description of TASS
- History of TASS
- Applications in NASA Programs
  - Windshear Program
  - Aviation Safety
    - TPAWS
  - Aircraft Spacing for Wake Vortices
    - AVOSS / WAKEVAS
- Summary

TERMINAL AREA SIMULATION SYSTEM (TASS)

- 3-D Large Eddy Simulation (LES) Model
- Meteorological Framework
- Prognostic Equations for:

3-Components of Velocity	- Pressure
Potential Temperature	- Rain
Water Vapor	- Snow
Liquid Cloud Droplets	- Hail / Graupel
Cloud Ice Crystals	- Dust / Insects

- Includes surface stress and ground heat flux parameterizations
- Accepts vertical profiles of winds, temperature, and moisture as input
- Contains roughly 60 microphysical submodels

What is TASS?

- Time-dependent, nonhydrostatic, compressible, primitive equation set.
- Meteorological framework with option for either three-dimensional or two-dimensional simulations.
- Large Eddy Simulation model with sub_grid-scale turbulence closure – Grid-scale turbulence explicitly computed, while effects of subgrid-scale turbulence modeled by Smagorinsky model with modifications for stratification and flow rotation.
- Optional conditions for lateral, top, and ground boundaries.
- Explicit numerical schemes, quadratic conservative, time-split compressible—accurate, highly efficient, and essentially free of numerical diffusion. Space derivatives computed on Arakawa C-grid staggered mesh with 4th-order accuracy for convective terms.
- Prognostic equations for vapor and atmospheric water substance (e.g. cloud droplets, rain, snow, hail, ice crystals). Large set of microphysical-parameterization models.
- Model applicable to meso-γ and microscale atmospheric phenomenon. Initialization modules for simulation of convective storms, microbursts, atmospheric boundary layer turbulence, convectively induced turbulence, urban fires, nuclear cloud rise, and aircraft wake vortices.
- Accepts vertical profiles of environmental temperature, moisture and winds as input.
- Output includes time-dependent, three-dimensional fields for atmospheric winds, temperature, pressure, and moisture.
- 60,000 lines of Fortran Code that Requires Supercomputer Resources.

TASS Governing Equations

Momentum:

$$\frac{\partial u_i}{\partial t} + \frac{H}{\rho_o}\frac{\partial p}{\partial x_i} = -\frac{\partial u_i u_j}{\partial x_j} + u_i \frac{\partial u_j}{\partial x_j} + g\,(H-1)\,\delta_{i3} + \frac{1}{\rho_o}\frac{\partial}{\partial x_j}\rho_o K_M \left[\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\frac{\partial u_k}{\partial x_k}\delta_{ij}\right]$$

Buoyancy:

$$H = \left(\frac{\theta}{\theta_o} - \frac{p\,C_v}{P_o C_p}\right)\left[1 + 0.61(Q_v - Q_{vo}) - Q_T\right]$$

Pressure:

$$\frac{\partial p}{\partial t} + \frac{C_p P}{C_V}\frac{\partial u_j}{\partial x_j} = \rho_o\, g\, u_j\, \delta_{j3}$$

Temperature:

$$\frac{\partial \theta}{\partial t} = -\frac{1}{\rho_o}\frac{\partial \theta \rho_o u_j}{\partial x_j} + \frac{\theta}{\rho_o}\frac{\partial \rho_o u_j}{\partial x_j} + \frac{1}{\rho_o}\frac{\partial}{\partial x_j}\left[\rho_o K_H \frac{\partial \theta}{\partial x_j}\right] + \frac{L\theta}{T\,C_p} S$$

Scalars:

$$\frac{\partial Q}{\partial t} = -\frac{1}{\rho_o}\frac{\partial Q \rho_o u_j}{\partial x_j} + \frac{Q}{\rho_o}\frac{\partial \rho_o u_j}{\partial x_j} + \frac{1}{\rho_o}\frac{\partial}{\partial x_j}\left[\rho_o K_H \frac{\partial Q}{\partial x_j}\right] + S$$

Subgrid Diffusion:

$$K_M = l_s^2 \sqrt{\frac{\partial u_i}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}\left(\frac{\partial u_k}{\partial x_k}\right)^2} \bullet \sqrt{1 - \alpha_1 Ri_1 - \alpha_2 Ri_r}$$

TASS NUMERICS

Prognostic Variable	Time Derivative	Advective Derivatives
Momentum, and Pressure	time-split, 2nd-Order Adams-Bashforth *and/or Modified Adams-Bashforth*	Centered, *4^{th}-Order Quadratic Conservative*
Temperature, Water Vapor, Water Substance, Dust, and etc.	Third-Order time/space with Upstream-Biased Quadratic Interpolation (Leonard, 1979)	

TASS Microphysical Interactions

From \ To	Water Vapor	Cloud Droplets	Ice Crystals	Rain	Snow	Hail/Graupel
Water Vapor		Condensation	Deposition	Condensation	Deposition	Deposition
Cloud Droplets	Evaporation		Riming & Spontaneous Freezing	Autoconversion & Collection by rain	Collection by snow	Collection by hail & Snow riming
Ice Crystals	Sublimation	Melting			Autoconversion & collection by snow	Collection by hail & Rain accretion of ice
Rain	Evaporation	Hail shedding collected cloud water			Collection by snow	Collection by hail, Rain accretion of ice, Rain accretion of snow & Spontaneous freezing
Snow	Sublimation			Melting		Collection by hail, Rain accretion of snow & Snow riming
Hail	Sublimation	Melting		Melting		

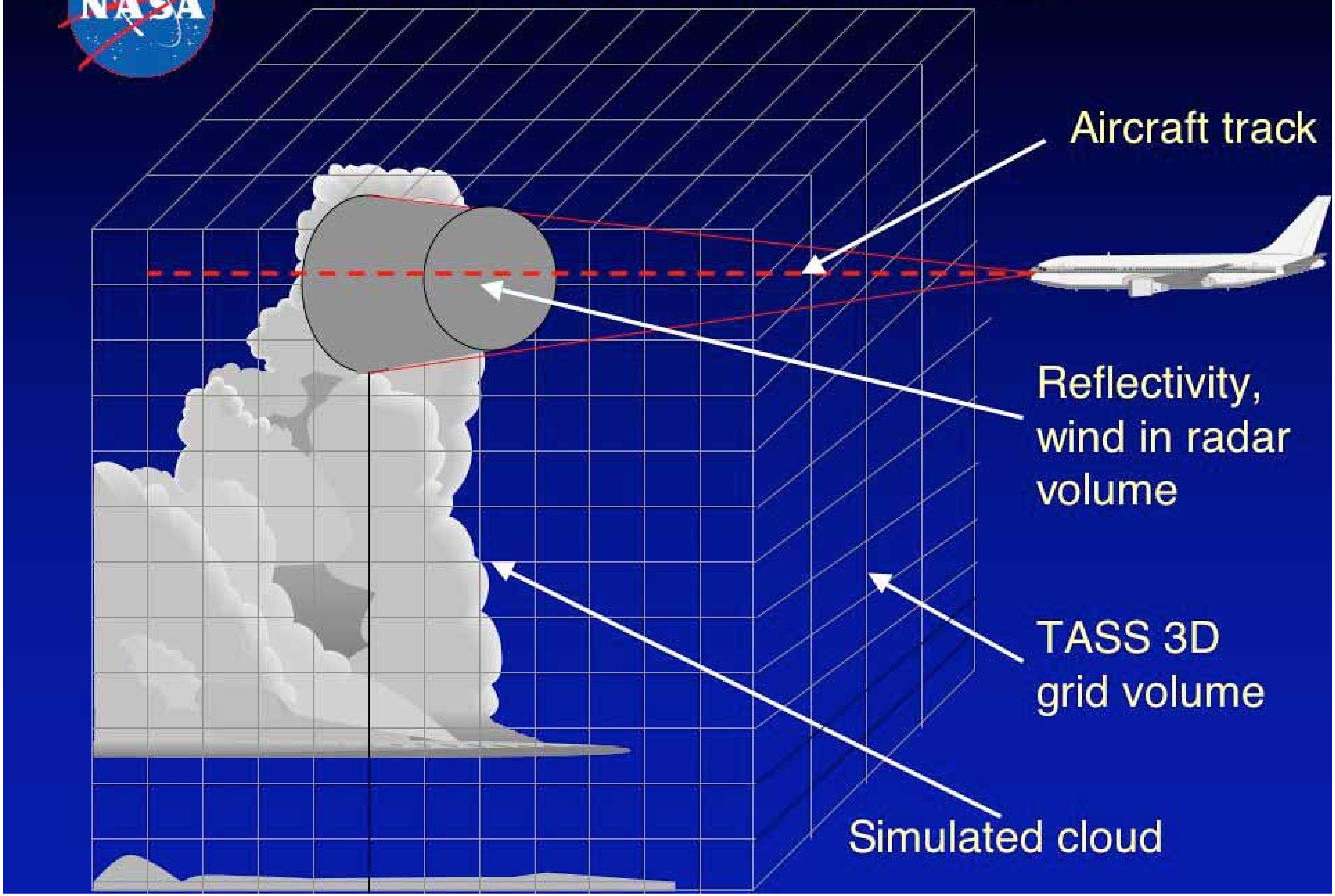
Numerical modeling with TASS Provides:

- Realistic data sets for sensor evaluation
- Realistic data sets for hazard analysis
- Realistic data sets for flight simulation studies
- Characterization based on parametric and case studies
- Guidance for development of engineering and real-time prediction models; e.g., wake prediction models
- Examination of outliers in field studies

Numerical modeling with TASS Provides:

- Realistic three-dimensional data sets
  - Large Volume of data with high resolution
  - Multiple variables that are physically consistent
  - Can examine by means of multiple paths
  - Many scenarios and relevant cases can be examined
- Overcomes limitations to observed, analytical, and empirical datsets such as
  - Observed within limited region or for a limited number of variables
  - More realistic the analytical formulas and empirical models

Airborne Sensor Simulation



TASS -- History

- Development began in 1983 for NASA/FAA Windshear Program.
- Recently applied in NASA's Wake Vortex Program for improving airport capacity (i.e. AVOSS)
- Currently used in NASA/FAA program to study convectively induced turbulence and improve aviation safety
- Validated and verified in simulations of cumulus convection, severe local storms, nuclear cloud rise, microburst wind shear, atmospheric boundary layer turbulence, convective induced turbulence, wake vortex transport and decay
- Produced data sets for FAA certification of onboard windshear sensors
- Produced data sets for potential certification of onboard turbulence radars
- Supported NTSB investigations of 1994 Charlotte, 1999 Little Rock accidents, as well as the recent American Airlines flight 587 crash at JFK

Microbursts / Low-Level Wind Shear

- Between 1964 and 1985, wind shear directly caused or contributed to 26 major civil transport aircraft accidents in the U.S. that led to 620 deaths and 200 injuries.

- The vast majority of accidents attributed to wind shear are in fact caused by microbursts, which is why the terms wind shear and microbursts are often used interchangeably

- Accidents occur during take-offs and landings as aircraft encountered a change in horizontal wind along the flight path, resulting in a loss of lift. This hazard is amplified by downdraft air which feeds the spreading outflow.

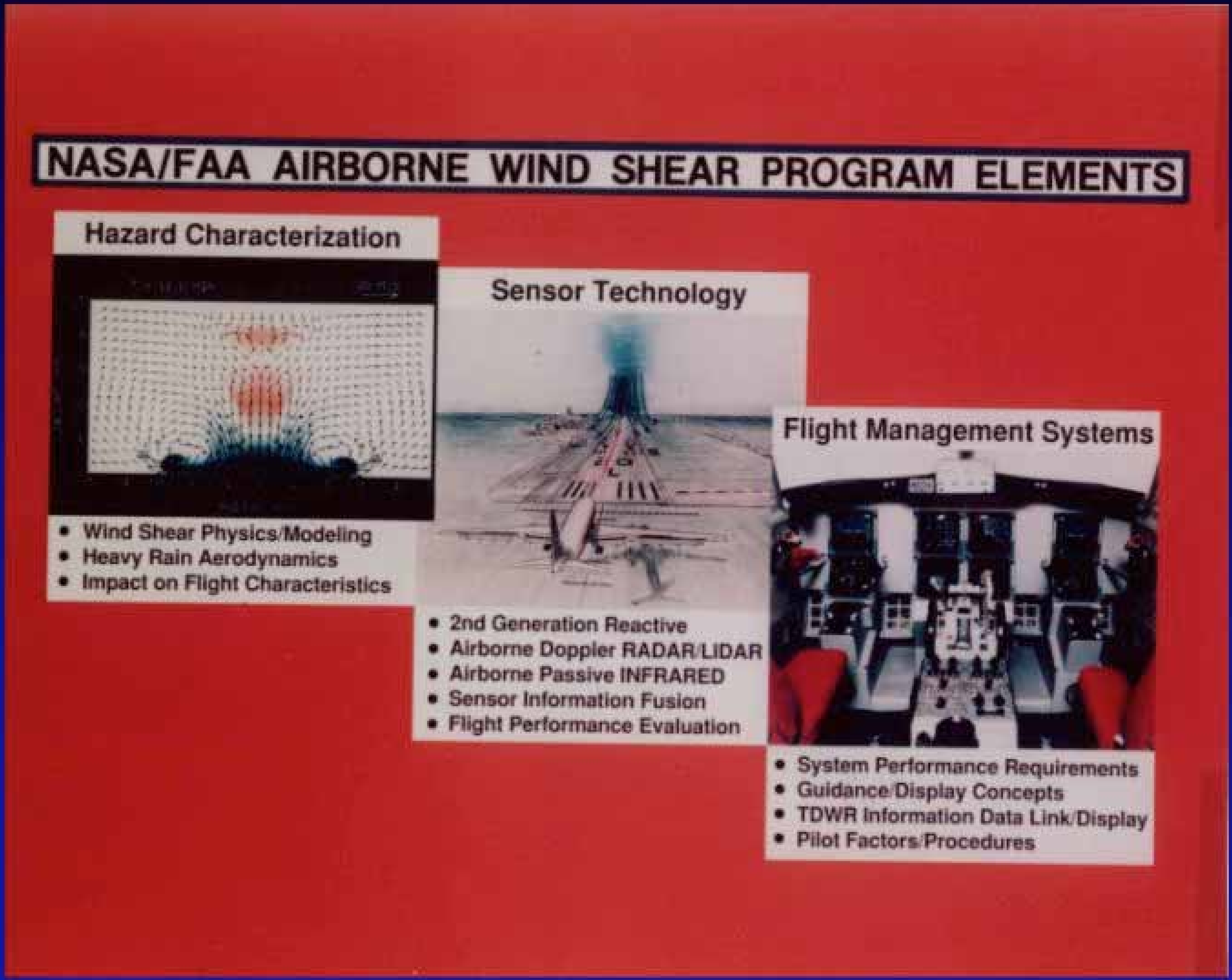
1. WIND-SHEAR CONDITIONS LIKE THOSE shown in this diagram of an aircraft over an airport runway pose a serious risk to aircraft landings and takeoffs.

Microburst

What is a Microburst?

- Rapidly Descending Column of Air, that Impacts Ground Creating Strong Horizontal Outflow
- Driven by Cooling from Evaporation, Sublimation, and Melting of Precipitation
- Diameter of Outflow Winds Greater than 1 KM
- Horizontal Wind Change Exceeds 10 m/s over a Distance less than 4 Km
- Microburst Intensify Quickly — from Quiescent to Severe in 2 to 4 minutes
- "Dry" Microburst accompanied by little or no Rain, "Wet" accompanied by Heavy Precipitation.

NASA/FAA Windshear Program Elements



Supporting Development of Sensor Technology

Microwave Doppler Radar

- NASA led development of research radar system
  - Key concerns
    - detection of low reflectivity microbursts (i.e., "dry" microbursts with radar reflectivity < 35 dBZ)
    - rejection of ground clutter during approach operations
- Key tool in development was a comprehensive simulation model of radar system that was interfaced with TASS and could utilize various ground clutter models (both analytic and test-data-derived)

Supporting Development of Hazard Characterization

- TASS data sets supported the development and testing of the "F-Factor," a nondimensional index that characterizes the effect of windshear on the aircraft energy state

$$F \equiv \frac{\dot{U}_x}{g} - \frac{w}{V_a}$$

- The FAA has selected 0.105 as the Hazard Threshold for Look-Ahead Windshear Alerting Systems. Hazard determined from 1 km-average F-Factor
- Further information available at: http://techreports.larc.nasa.gov/ltrs/PDF/2000/mtg/NASA-2000-9caram-fhp.pdf

5th (and Final) Combined Manufacturers' & Technologists' Airborne Wind Shear Review Meeting

NASA's AIRBORNE DOPPLER RADAR FOR DETECTION OF HAZARDOUS WIND SHEAR
Flight Results

NASA Langley Research Center

F-FACTOR CALCULATION

Measured	$F_H = \frac{V_G}{g} \times \frac{\partial V_R}{\partial R}$	
Calculated	$F_V = F_H \left(2 \frac{g}{V_G} \frac{ALT}{V_A} \right)$	for $F_H > 0$
Threshold	$F_T = F_H + F_V$	

$F_H \equiv$ **Horizontal component of hazard index**

$F_V \equiv$ **Vertical component of hazard index**

$\frac{\partial V_R}{\partial R} \equiv$ **Spatial shear of radially measured wind field**

$V_A \equiv$ **Aircraft airspeed**

$V_G \equiv$ **Aircraft groundspeed**

ALT $\equiv$ **Aircraft altitude (AGL)**

Technology Transfer

FAA Certification Support

- In 1990, working group formed of personnel from FAA, NASA, airlines listed under FAA exemption 5256, avionics vendors, and airframe manufacturers
  - Charter: develop system level requirements and certification methodology for forward-look windshear detection systems
- Working group was tremendous catalyst for technology and knowledge transfer from NASA researchers to FAA and industry
- NASA contributions to FAA certification process for these systems
  - Participated in developing and documenting certification methodology
  - Participated in developing and documenting FAA Technical Standard Order on "Airborne Windshear Radar with Forward-Looking Windshear Capability"
  - Developed event database of seven windshear cases generated by TASS -- vendors must demonstrate, in simulation, performance of their systems in windshear and related meteorological conditions
  - Applied proposed certification methodology to NASA experimental windshear radar to exercise methodology and provide lessons learned to FAA and industry

Description of Windshear Certification Data Sets

Set Num	Simulation Description	Model Sim Time (min)	Stage of Evolution for Primary Microburs t	Approximate Peak 1-kilometer FBAR @ 150 kts	Approximate Diameter of Outflow @ Peak _V (km)	Approximate Microburst Core Reflectivity (dBZ)	Intervening Rain	Symmetry
1	DFW Accident Case, Wet Microburst, Rain and Hail	11	Peak Intensity	0.2	3.5	55	No	Axisymmetric
2	6/20/91 Orlando, Florida, NASA Research Flight, Wet Microburst	37	Peak Intensity	0.19	3.5	50	Yes	Rough Symmetry
3	7/11/88 Denver Colorado Incident Case, Multiple Microburst	49 51	Develop-ing Near Peak	0.08 0.2	3 1.5 - 3	35 20 - 40	Light Yes	Varies Between Microbursts
4	7/14/82 Denver, Colorado, Stable Layer, Warm Microburst	36	Past Peak but Quasi-Steady	0.29	1.0	27	No	Axisymmetric
5	7/8/89 Denver, Colorado, Very Dry Microburst	40 45	Near peak 2nd Pulse	0.18 0.16	3 3	17 – 20 5	No	Rough Symmetry Asymmetric
6	Derived Florida, Highly Asymmetric Microburst	14	Decaying	0.16	1	50	Light	Asymmetric
7	8/2/81 Knowlton, Montana, Gust Font	27	N/A	0.14	N/A	20 (in area of largest FBAR)	No	Asymmetric

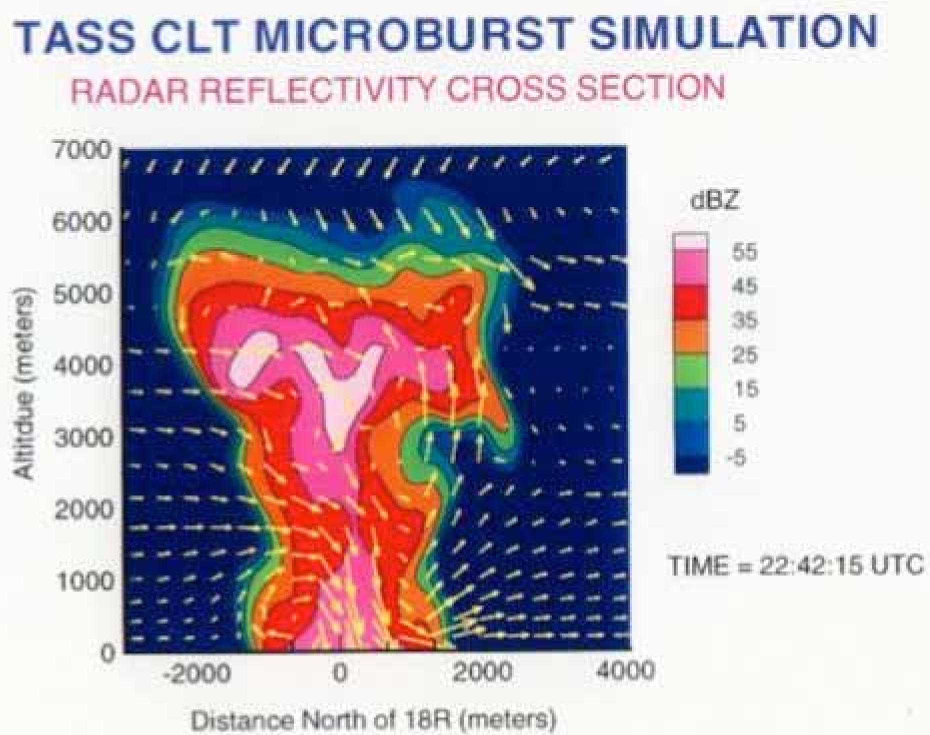
Technology Transfer

- NASA's Airborne Wind-Shear Detection and Avoidance Program (AWDAP) built the foundation for present commercially available wind-shear radar systems
- Today, nearly 4000 commercial airliners worldwide use wind-shear detection and alert systems based on NASA's AWDAP
- No major windshear accident has occurred in the last 10 years

Reconstructing a Windshear Accident

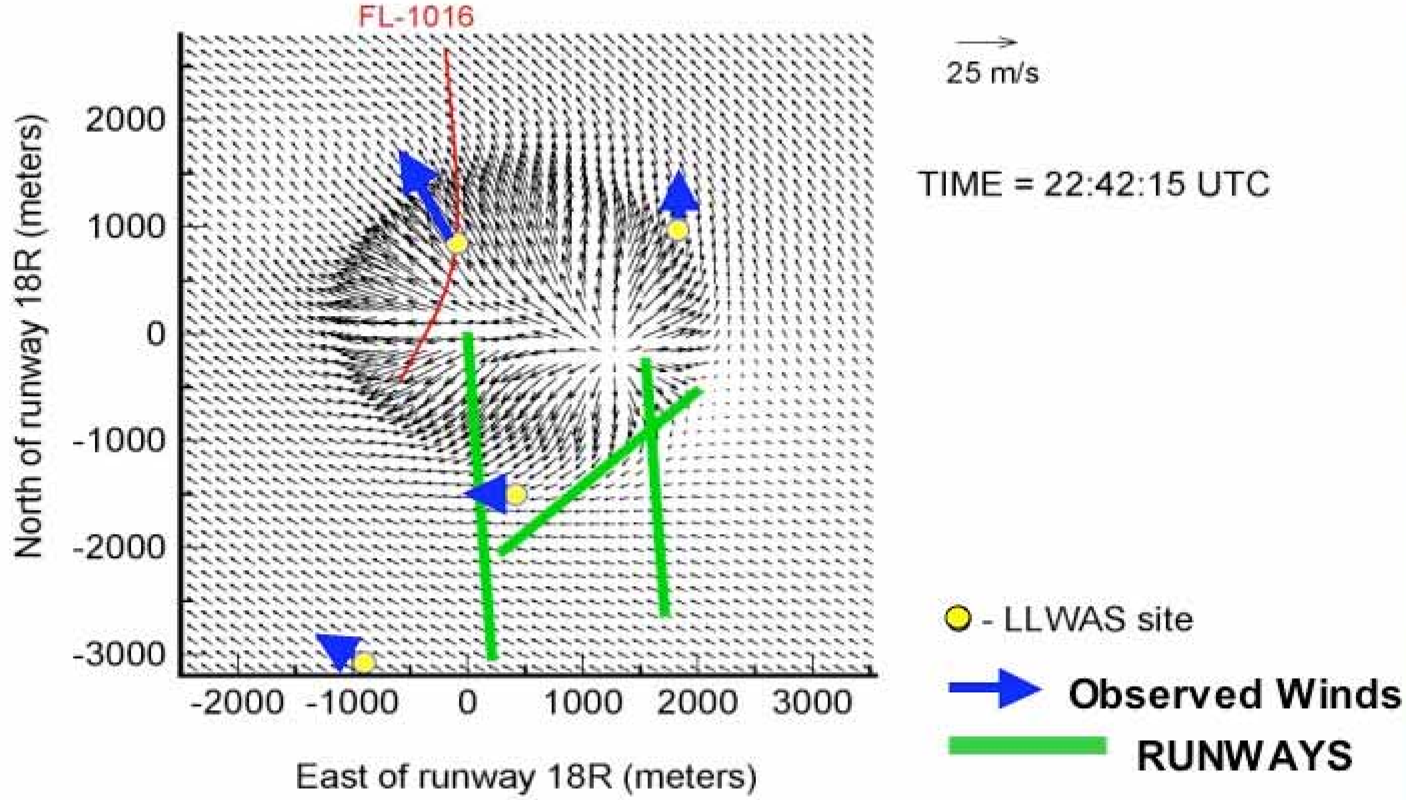
- USAir Flight 1016 crashed at Charlotte, NC on July 2, 1994 after appearing to have encountered a microburst while approaching runway 18R
- NASA was requested to support NTSB investigation and testify at September 21, 1994 public hearing
- NASA reconstructed meteorology at the time of the accident using TASS (Terminal Area Simulation System)
- TASS reconstruction compared with "observed data" from
  - LLWAS sensors
  - accident aircraft flight data recorder
  - Columbia, SC NEXRAD Radar (135 km away)
  - National Weather Service surface observations
  - eyewitness accounts

Simulated Radar Reflectivity and Wind Vectors

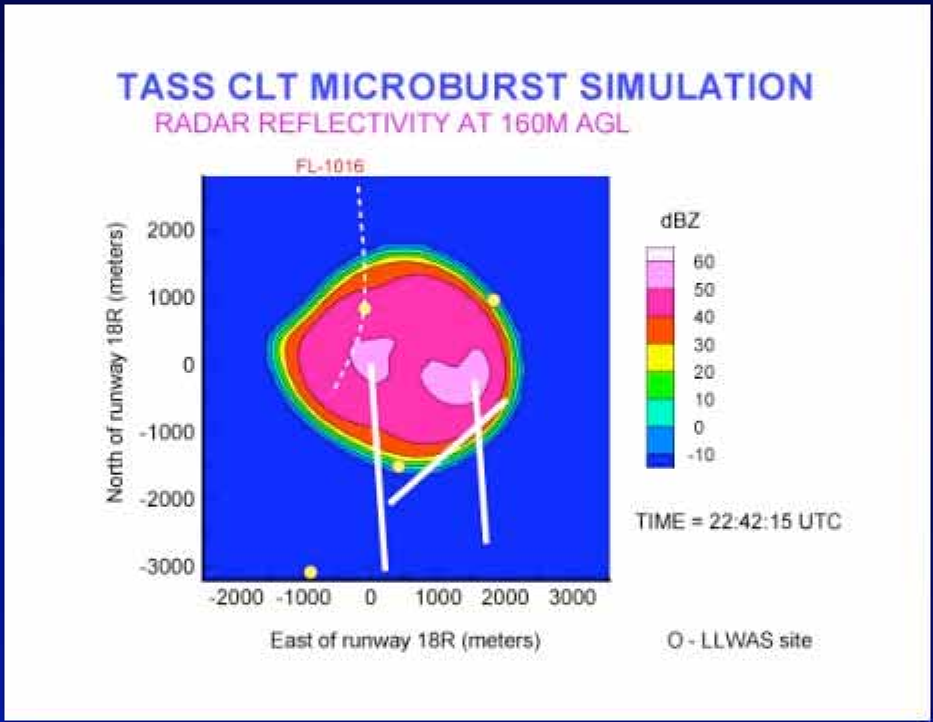


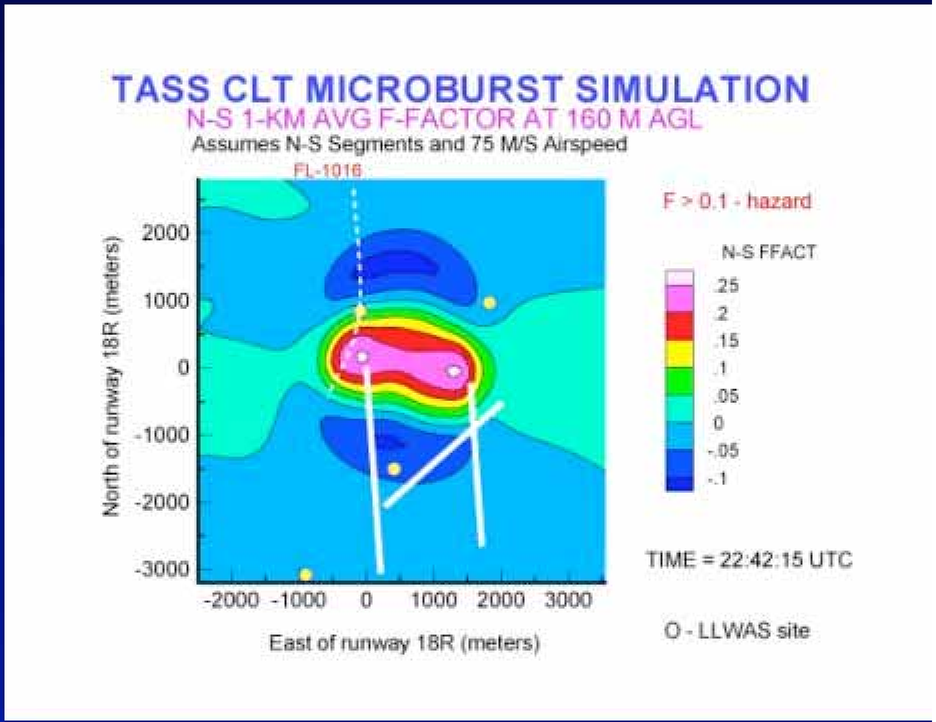
TASS CLT MICROBURST SIMULATION

HORIZONTAL WIND VECTORS AT 90 M AGL

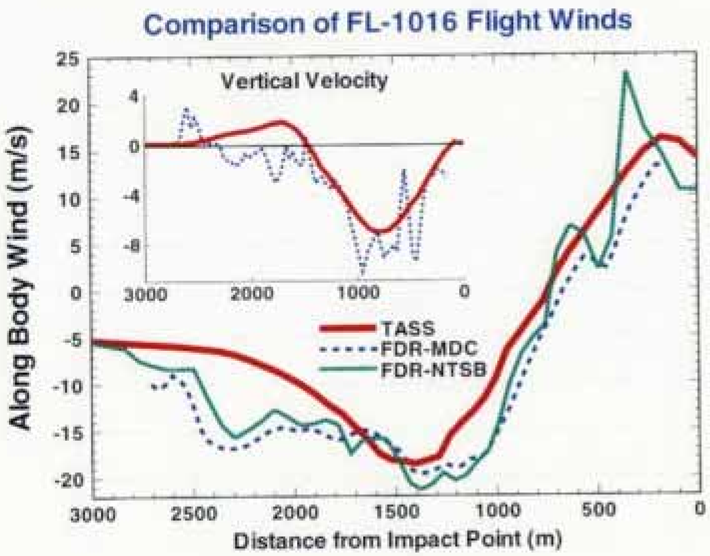


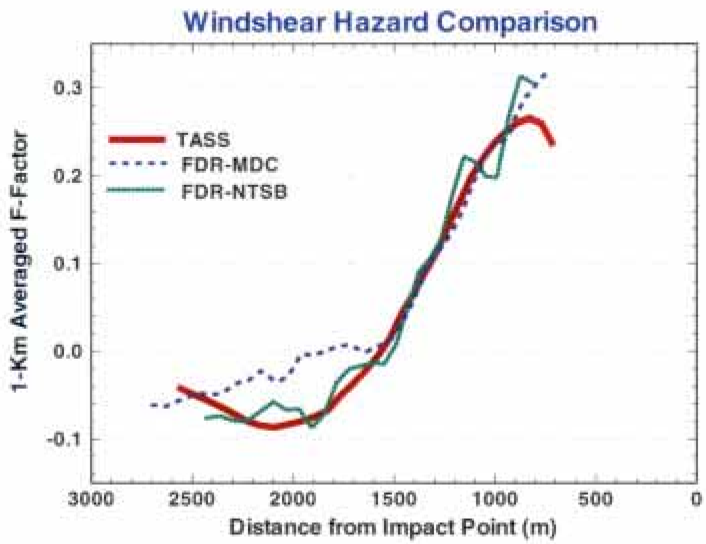
TASS Simulation of Charlotte Event





Comparison of winds and hazard along flight path



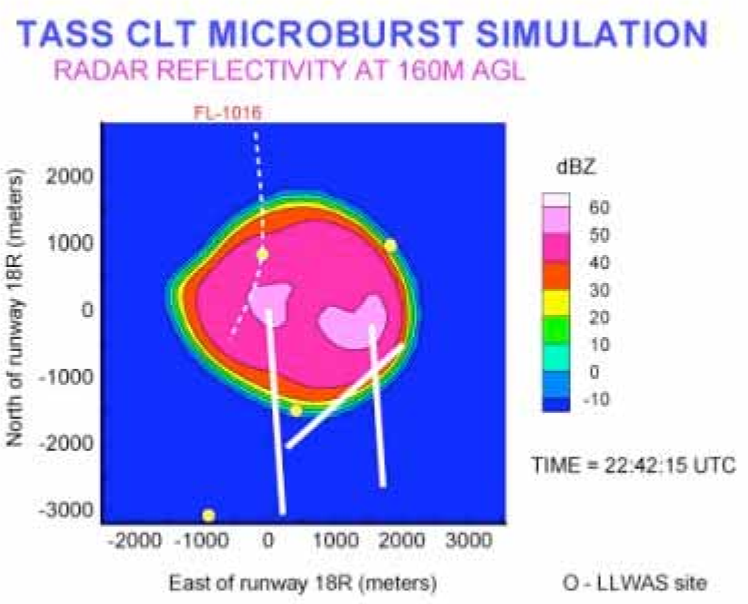


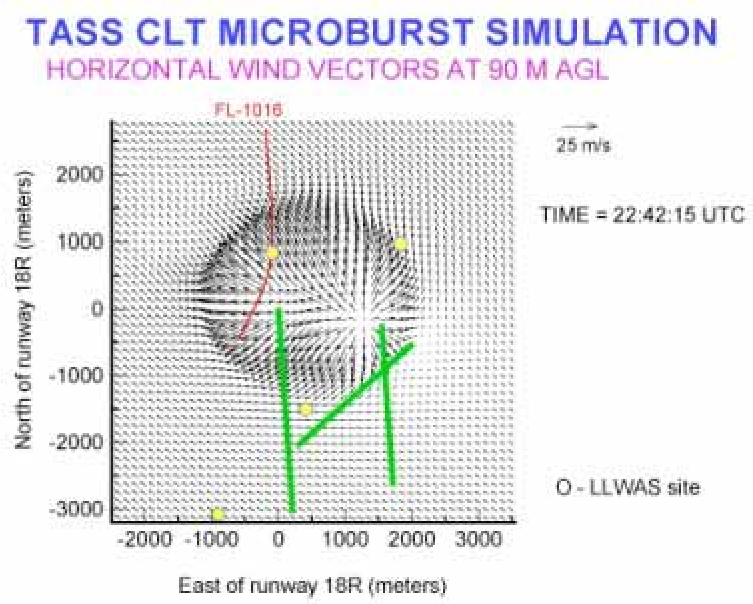
Airborne Windshear Radar Simulation: TASS Charlotte Data Set

- Aircraft assumed to be on approach along 3 - degree glide slope
- Assumes Philadelphia ground clutter
- Uses TASS data fields assuming microburst encounter at accident time

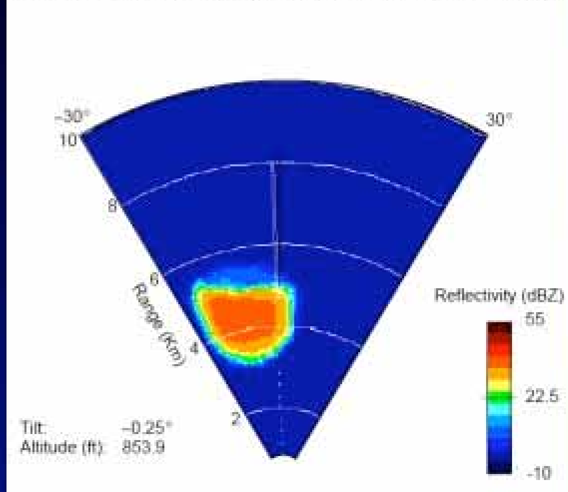
- Study suggest availability of airborne windshear radar may have prevented this accident

ADWRS Radar Simulation From Data Set

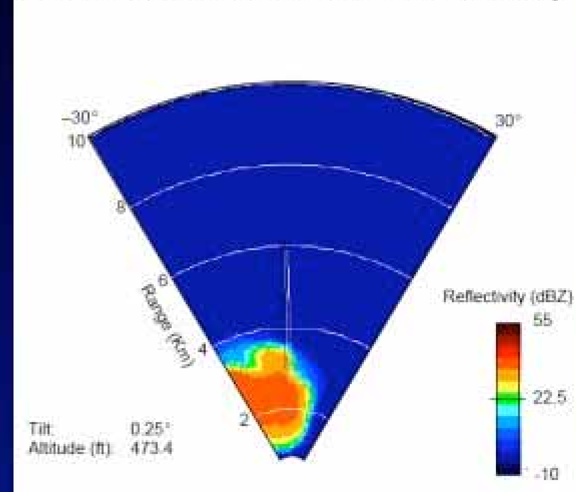




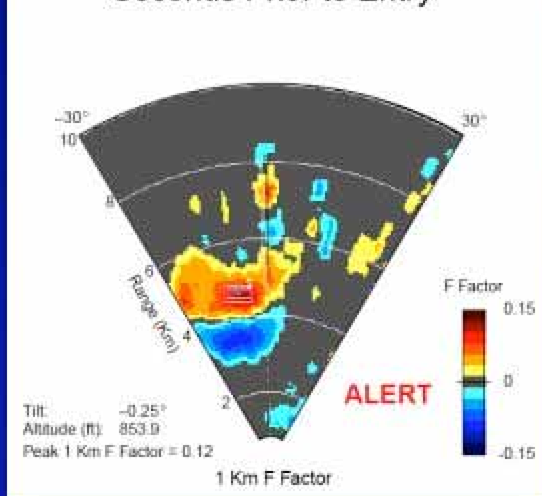
Simulated Radar Reflectivity Without Clutter 60-75 Seconds Prior to Entry



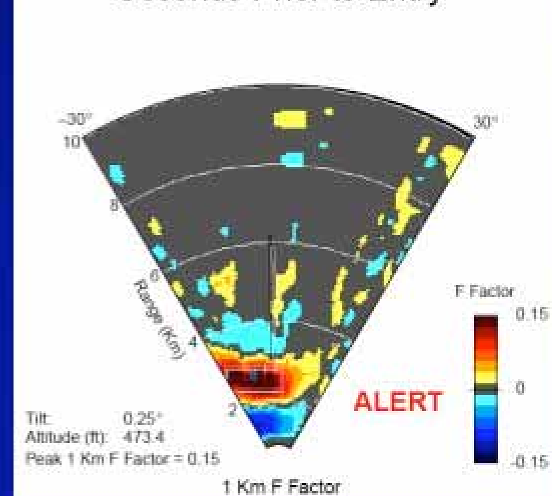
Simulated Radar Reflectivity Without Clutter 30-45 Seconds Prior to Entry



Simulated Hazard With Clutter 60-75 Seconds Prior to Entry



Simulated Hazard With Clutter 30-45 Seconds Prior to Entry

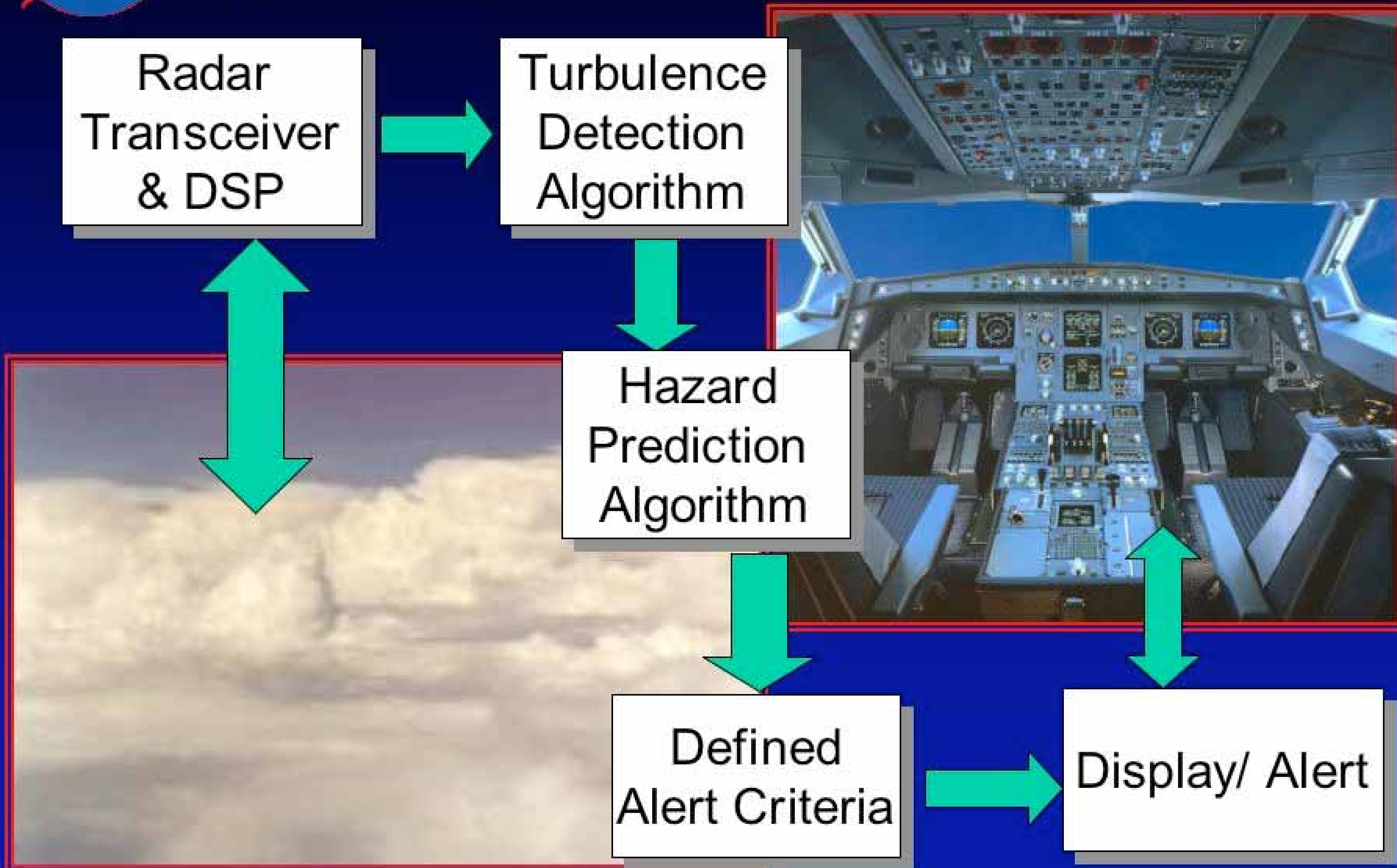


Turbulence Prediction and Warning Systems (TPAWS): Goals

- Provide warning to aircraft of imminent encounter with hazardous turbulence.
- Significantly reduce injuries aboard commercial jetliners due to in-flight encounters with turbulence
- Provide tool set to industry and FAA for anticipated certification of new turbulence prediction systems

Flight Turbulence, AvWx Safety Program

TPAWS End-to-End System Concept



RLB / PAR

TPAWS Tool Set

- Model Data Sets
- Hazard Tables
- Hazard Metrics
- ADWRS
- Scoring Tools

  - for testing airborne systems that are intended to detect turbulence hazard associated with atmospheric convection
  - useful for evaluation of detection system
  - available for anticipated FAA certification activity

Tool set components, reports, and data set descriptions can be found on TPAWS web site: http://tpaws.larc.nasa.gov/

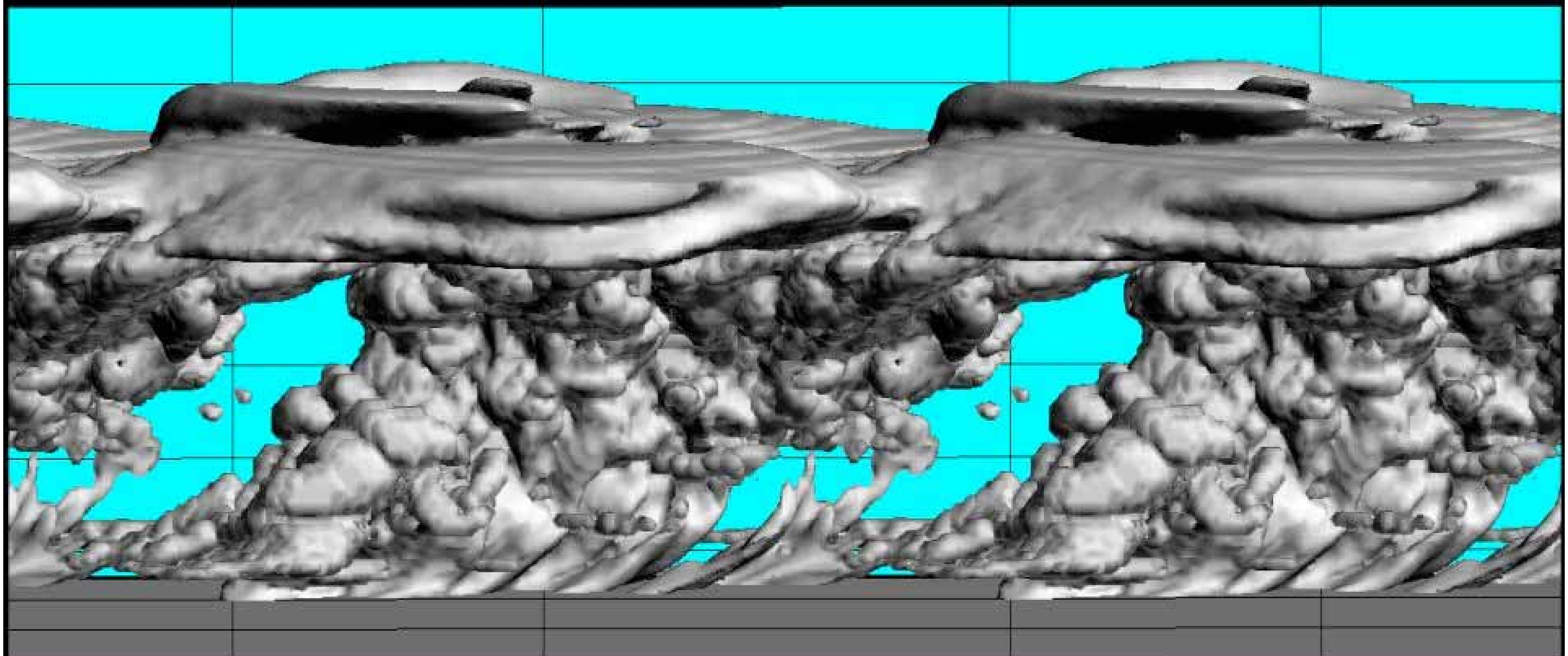
Turbulence Classification

- Convectively Induced Turbulence (CIT)
  - Most injuries from turbulence encounters associated with CIT
  - Aircraft encounters are usually unexpected and of short duration
  - Encounters occur when:
    - aircraft skirt around high reflectivity regions to minimize deviation from flight plan
    - convection appears invisible or benign from aircraft's radar
    - storm tops unexpected rise into the aircraft's flight path
    - aircraft are inadvertently vectored into convection by ATC
  - Intensity of turbulence not correlated with level of radar reflectivity
  - Many events are detectable with aircraft radar

Numerical Modeling Challenge

- Achieve high resolution resolving scales important for sensors and airplane response
- While assuming a large volume to correctly model the convection whose larger scales feed energy into the smaller scales of concern
- Obtaining the most representative environmental conditions to accurately model a specific case

TASS Simulation of Convective Line (Case-191-06) viewed from southeast



TPAWS Model Data Sets

- Event 191-06
  - Severe turbulence encountered at 10.3 *km* AGL on 14 Dec 2000 during NASA's TPAWS flight tests. Event associated with overshooting tops of a convective line across FL panhandle.
  - Data set contains severe turbulence in regions of low radar reflectivity.
- FOQA - Wilmington
  - Severe turbulence encountered by a commercial B-737 at 2.3 *km* AGL near Wilmington, DE, while on descent. Airliner vectored by ATC into leading edge of shallow convection with tops between 5-6 km.
  - Data set contains patches of moderate to severe turbulence in regions of low radar reflectivity.
- 232-10
  - Severe turbulence encountered by NASA's B-757 during spring 2002 flight test. Encounter occurred in IMC conditions with "ship's radar" displaying black and green. Exemplifies operational environment in which accidents occur due to turbulence.
  - Data set contains severe turbulence associated with low-reflectivity regions of rising cloud tops.

Tool Set Component: Hazard Analysis Algorithms

- Estimates of Hazard from Model Wind Fields needed for Truthing Radar Simulations
- RMS Normal Load obtained from σ_w using a moving box and hazard tables.
- Hazard tables based on aircraft:
  - Type
  - Weight
  - Altitude

Hazard Estimation of RMS Normal Load Moving Box Method

For any horizontal plane in the model data set, σ_w is computed using a moving box as:

$$\sigma_w(x,y) = \left[\frac{1}{L_x L_y} \int_{x-\frac{L_x}{2}}^{x+\frac{L_x}{2}} \int_{y-\frac{L_y}{2}}^{y+\frac{L_y}{2}} \{ w(x',y') - \overline{w}(x,y) \}^2 \, dx' dy' \right]^{\frac{1}{2}}$$

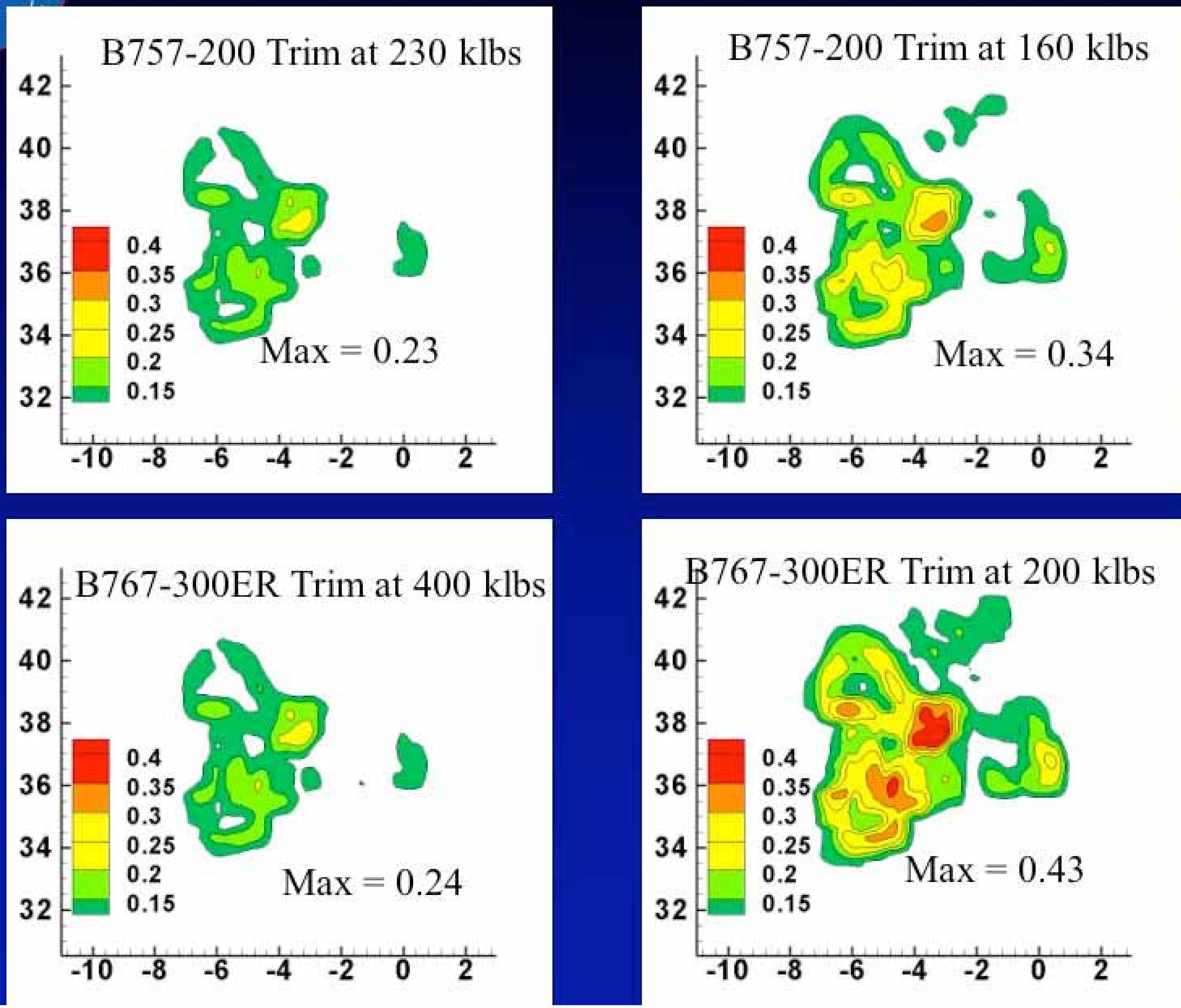
where the averaging interval is $L_x = L_y = t_1 V_a$,
V_a is airspeed, $t_1 = 5$ *sec*, *w* is vertical wind, and the box-averaged w is:

$$\overline{w}(x,y) = \frac{1}{L_x L_y} \int_{x-\frac{L_x}{2}}^{x+\frac{L_x}{2}} \int_{y-\frac{L_y}{2}}^{y+\frac{L_y}{2}} w(x',y') \, dx' dy'$$

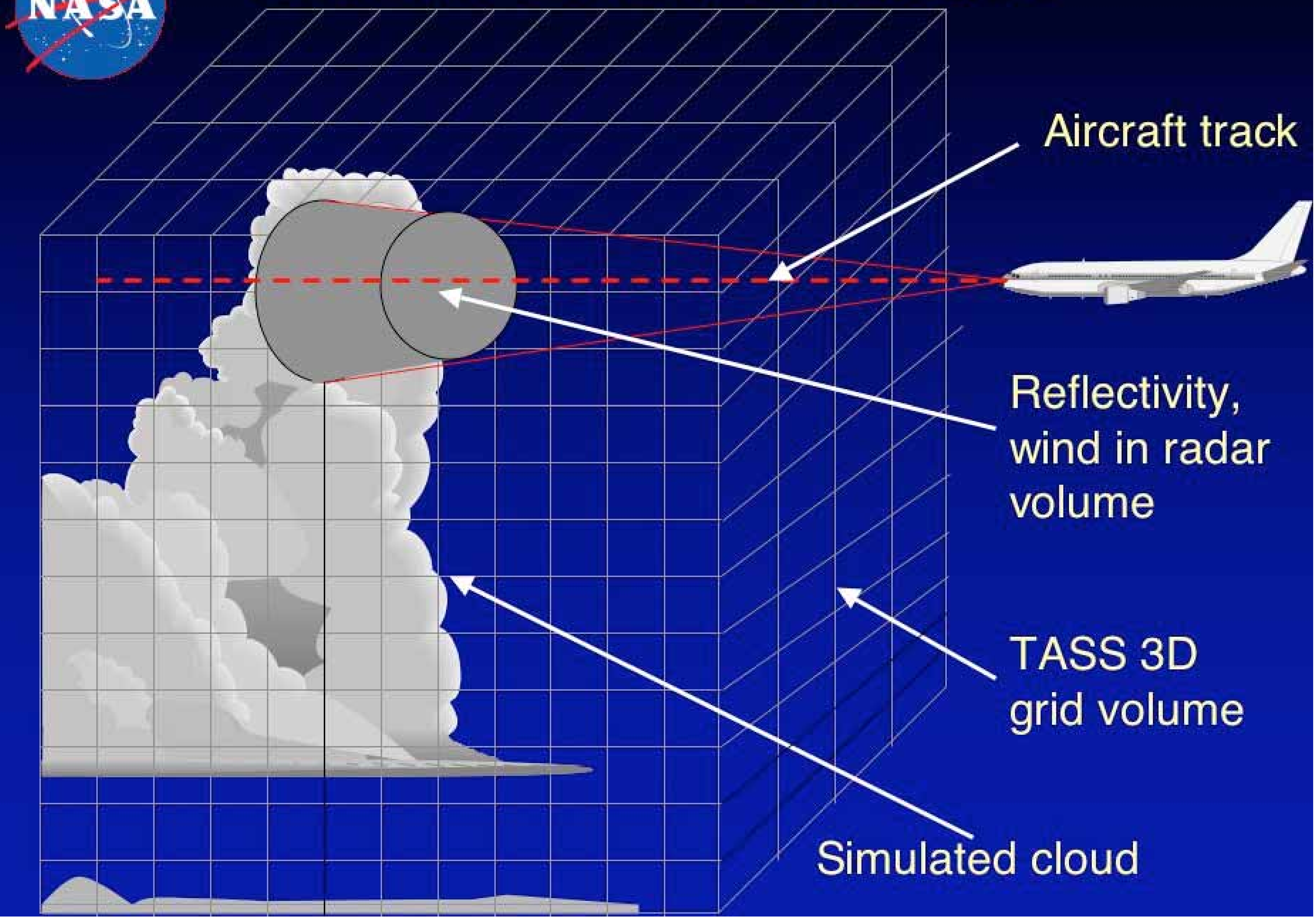
RMS normal load computed from σ_w using hazard tables

Horizontal Cross-Section of 100 m FLR 191-6 Data Set

RMS acceleration from at 10.3 km Elevation

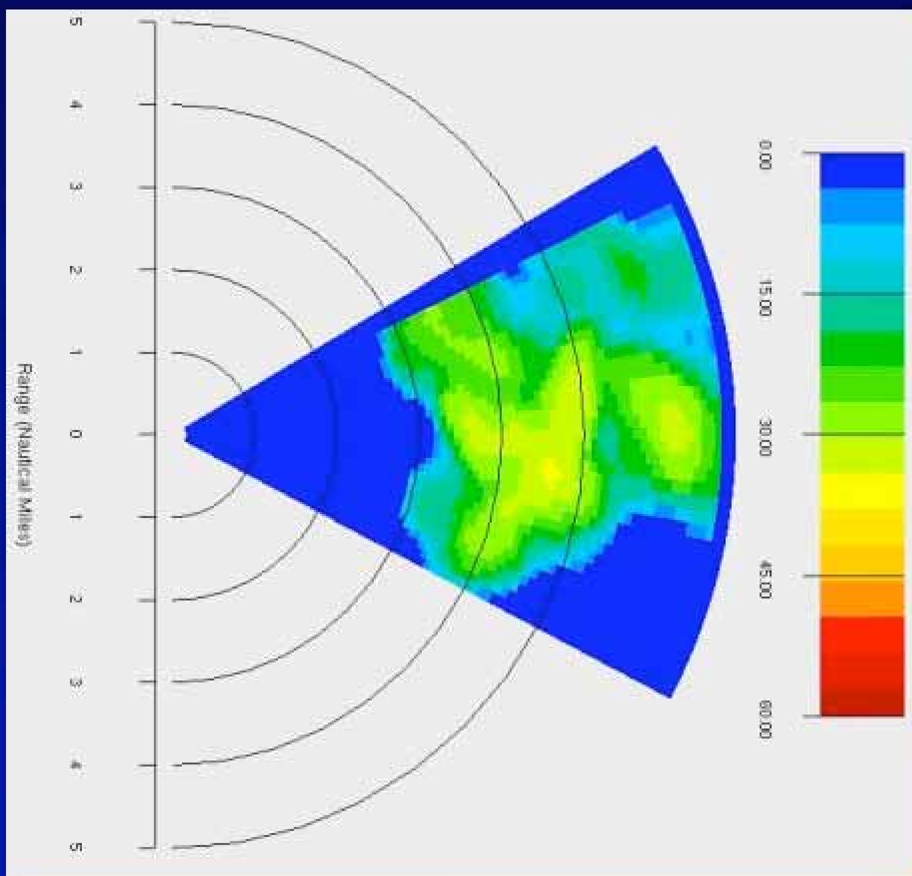


Airborne Sensor Simulation

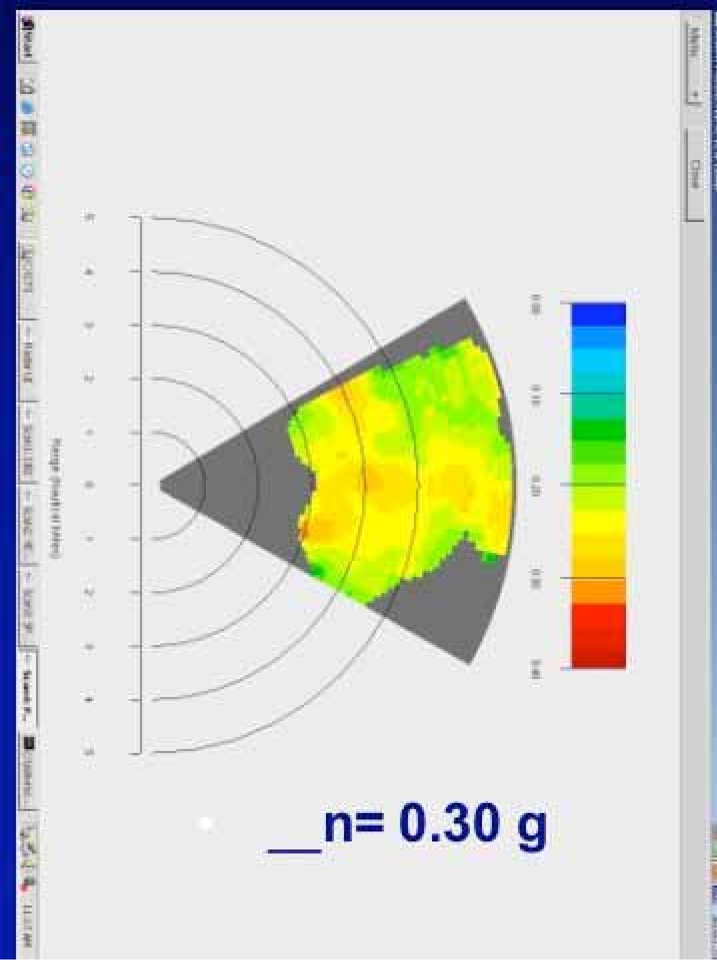


191-06 Radar Simulation

Radar Reflectivity



Hazard



Technology Transfer

- Tool set made available to industry and FAA
- Turbulence prediction system field tested during NASA B-757 flight tests
- Prototype turbulence prediction systems currently being tested by Delta on revenue-generating flights

Efficient Aircraft Spacing for Increased Capacity

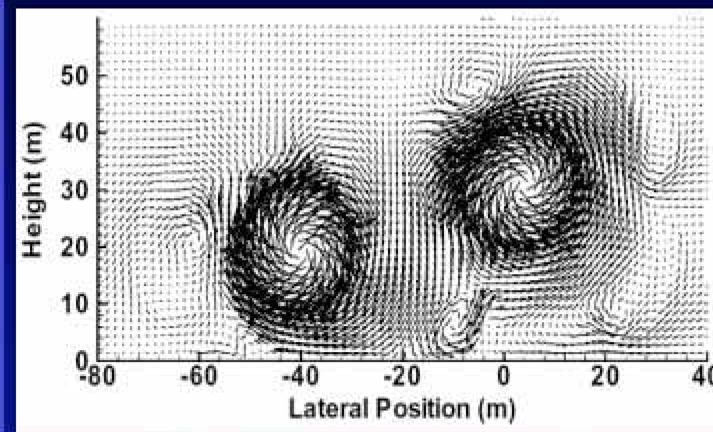
- TASS supported the Aircraft Vortex Spacing System (AVOSS) which competed with a successful field demonstration in 2000
- TASS is currently supporting the WakeVAS program (successor to AVOSS)

WakeVAS Program Needs

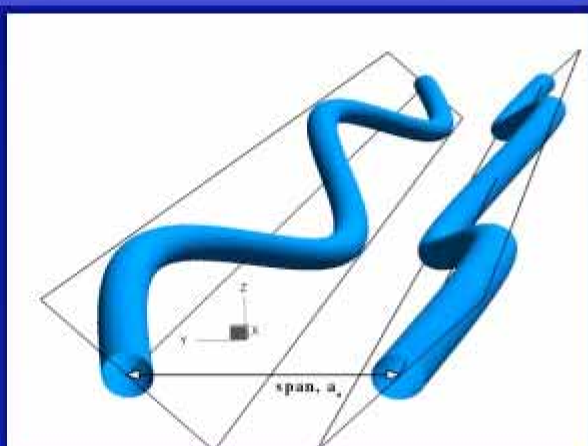
- **Predict aircraft spacings from 0-30 minutes**
  - based on wake vortex transport and decay
  - dependent upon real-time weather conditions;
  - using aircraft type, weight, and speed
- **Predict aircraft spacings over next 3-4 hours. Needed for planning traffic activity**
  - dependent upon <u>predicted</u> weather conditions;
  - using aircraft type, weight, and speed
- **Define acceptable hazard criteria**

Wake Vortex Predictor

Wake/Weather Sensing



Numerical/Parametric Studies



Wake Characterization

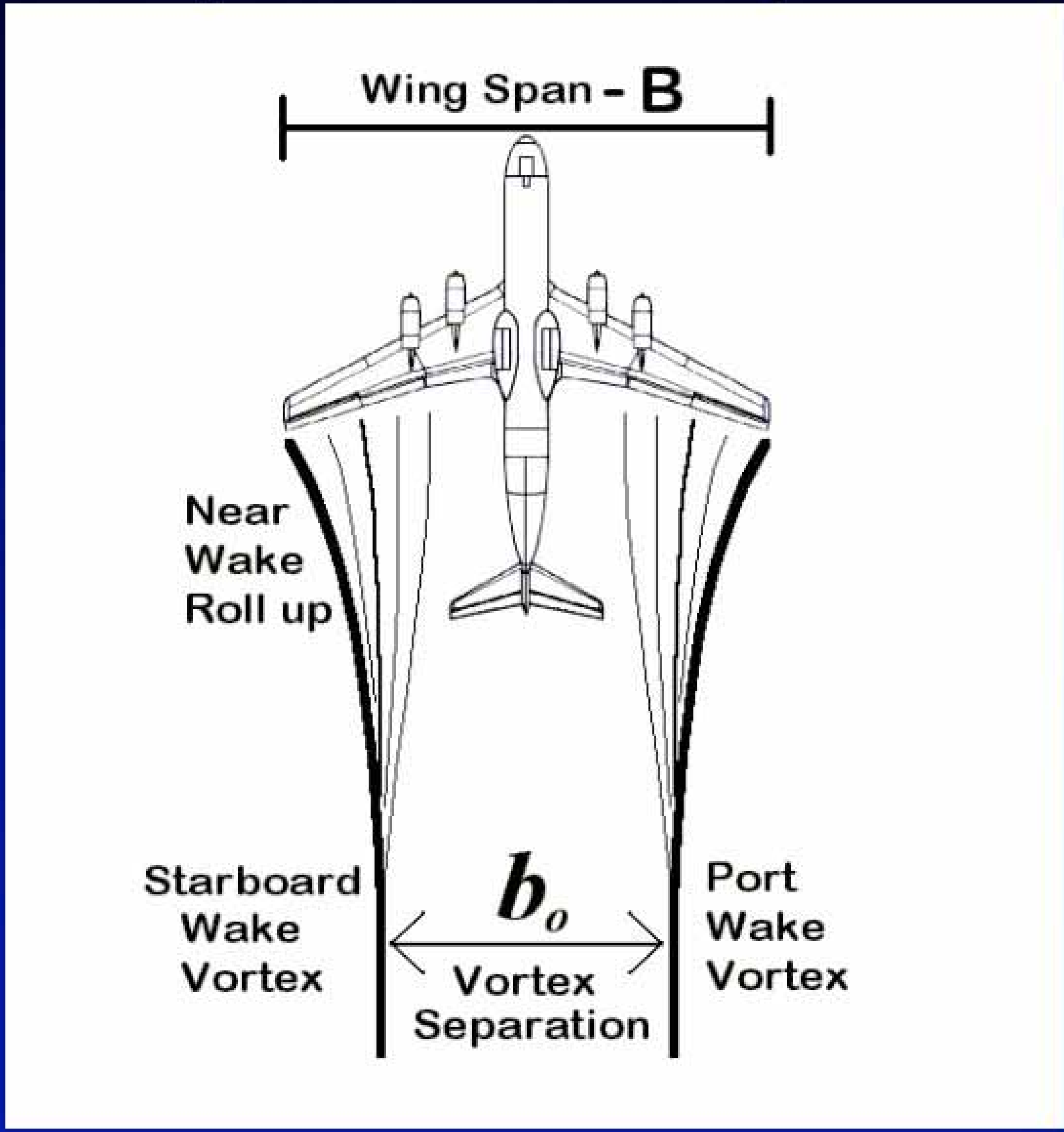
$$\frac{d\bar{\Gamma}}{dT} = -F(T)\frac{\beta_2+\beta_3 N^{*4}}{2}$$
$$* \operatorname{sech} h^2\left[(\beta_2 + \beta_3 N^{*4})(T - T_{ss}) - \alpha_2\right]$$
$$- c_2 \varepsilon^* \bar{\Gamma} - A_2 Z N^{*2}$$

Predictor Development

Modeling Challenge of Wake Vortices

- Achieve high resolution resolving scales important for airplane response and accurately modeling the decay mechanisms
  - Vortex core sizes ~ 1 m
  - Scales important to wake decay ~ 10-500 m
  - Wake vortex lengths >10 km
- While assuming a large volume to correctly model the larger scales that effect transport
- Obtaining the most representative environmental conditions and generating aircraft parameters to accurately model a specific case
- Early in AVOSS Program environmental influence on wake decay very controversial

Aircraft wake vortices in relation to generating aircraft (viewed from below)



The scale of a B-747 trailing vortex is made visible by industrial smoke in this sequence of photographs.

Characteristics of Vortex Decay

- Lifetime of aircraft wake vortices are from 15 seconds to several minutes
- Wake vortices have the longest lifetime within environments having weak turbulence and near-neutral thermal stratification
- Aircraft wake vortices decay primarily due to influences of:
  - –Intensity of ambient turbulence (eddy dissipation rate - ε)
  - –Magnitude of thermal stratification (Brunt-Vaisala frequency – N)
  - –Ground interaction
  - –Three-dimensional instabilities;
- Rapid vortex decay usually follows the onset of three-dimensional sinusoidal instabilities:

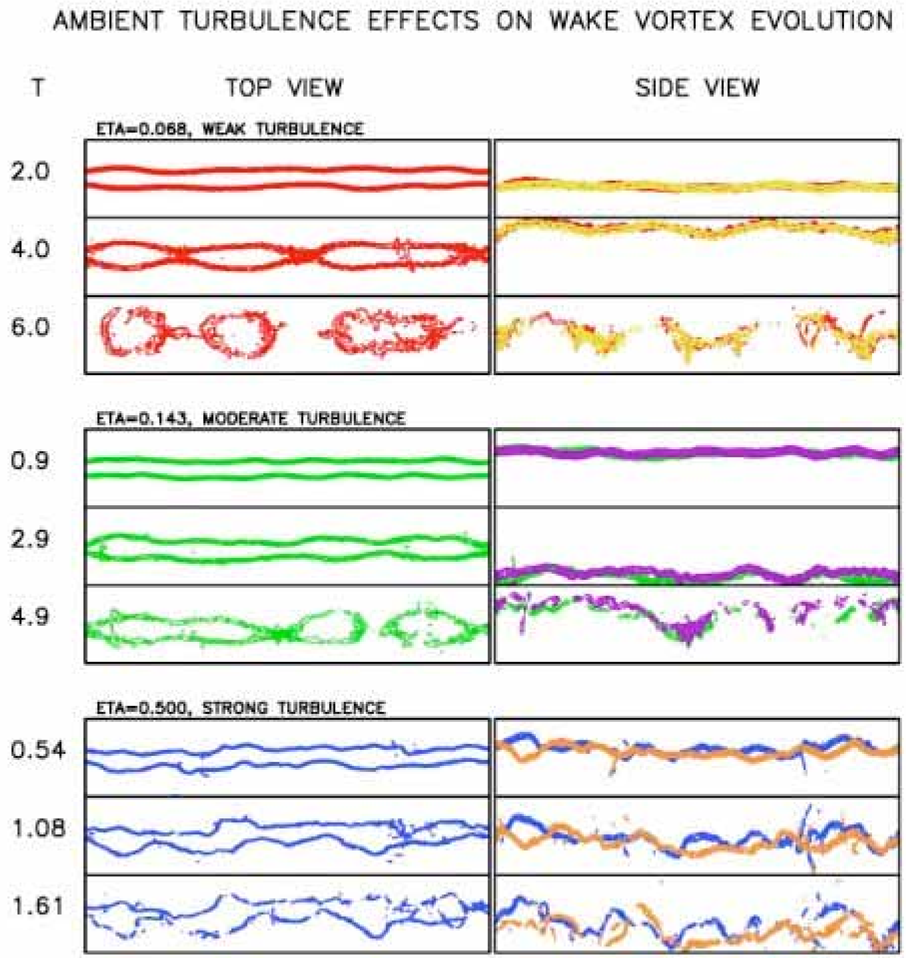
–Two forms: long-wave instability (wavelength ~ 4-9 b_o); short-wave instability (wavelength <3b_o)

–Onset time is a function of: aircraft parameters, ε, and N

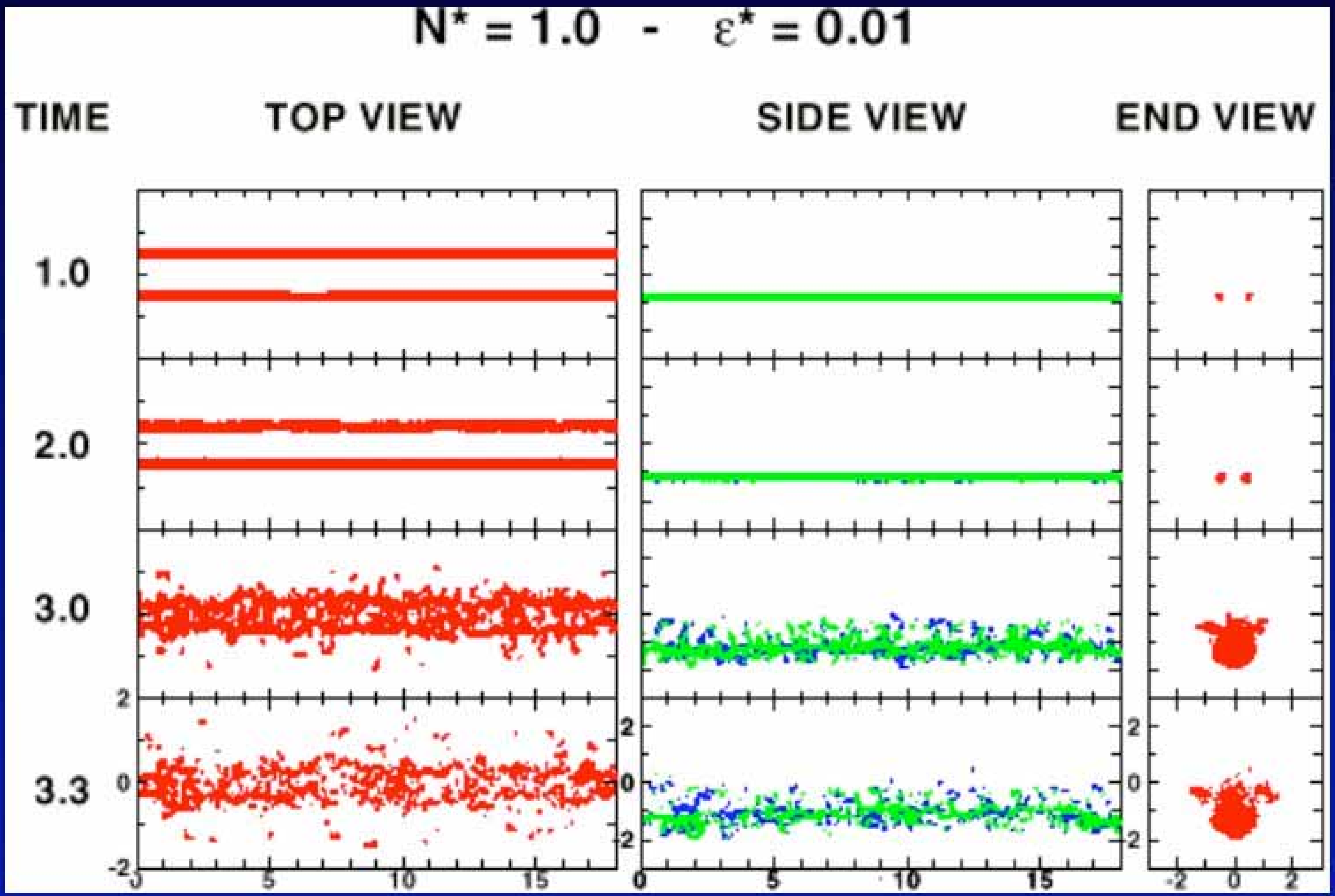
Characteristics of Vortex Transport

- Ambient turbulence and vortex instabilities may distort the wake vortex path
- Above the influence of the ground, wake vortices are transported laterally with the wind, while sinking due to mutual induction of the vortex pair
- The wake vortex sink rate is a function of the vortex circulation and aircraft span. Wake vortices from commercial jetliners sink initially at a speed of 1-3 *m/s*
- The sink rate decrease as the vortex circulation decays from environmental influences
- Crosswind shear may further reduce the sink rate and in some cases cause a wake vortex to rise
- Ambient turbulence influences the time of vortex pair linking; i.e. the time of occurrence of crude vortex rings that are elongated along the flight path.

Wake Sensitivity to Ambient Turbulence



Wake Decay due to Shortwave Instability



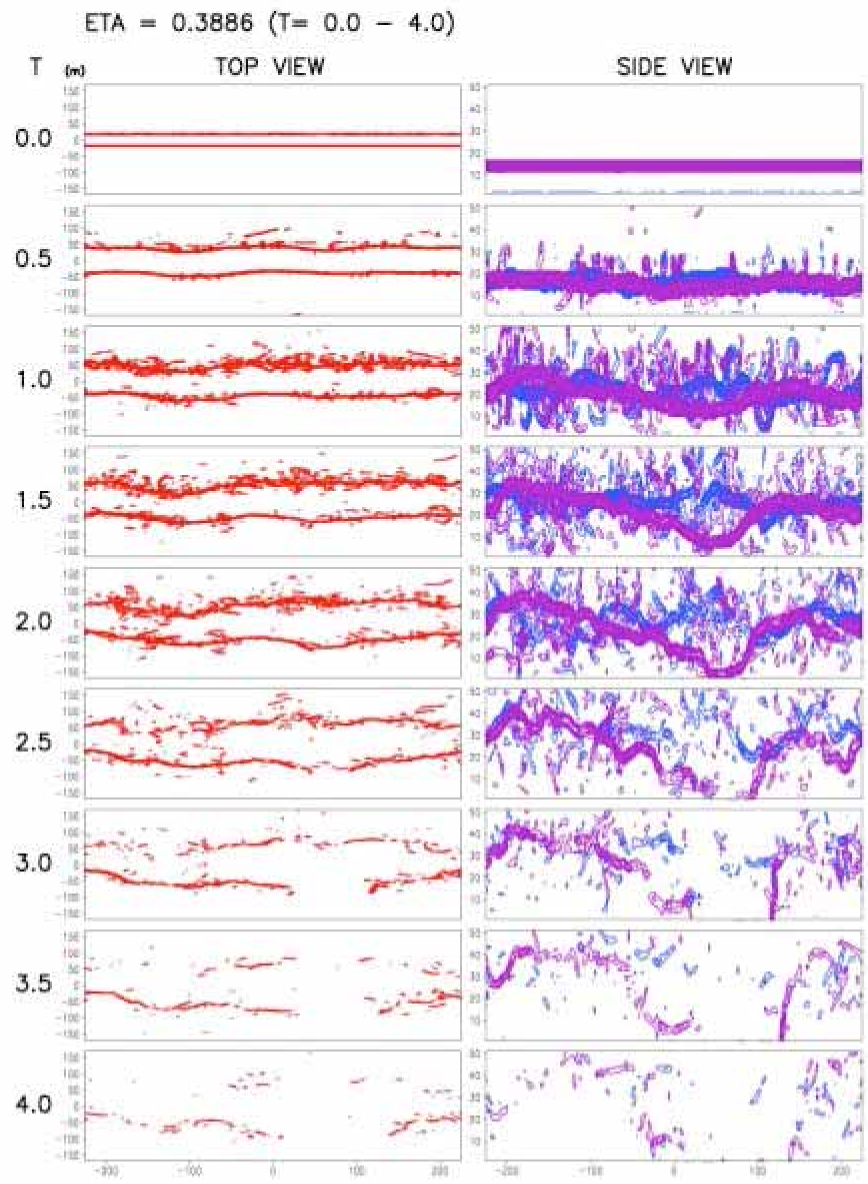
The TASS Driven Algorithms for Wake Prediction (TDAWP)

$$\frac{d^2 Z}{dT^2} = -\gamma\, \beta_1 \operatorname{sech}^2\left(\beta_1\left(T - T_L - \alpha_1\right)\right) - c_1\, Max\left\{\varepsilon^*, 0.08\right\}\frac{dZ}{dT} - A_1 Z\, N^{*2.5}$$

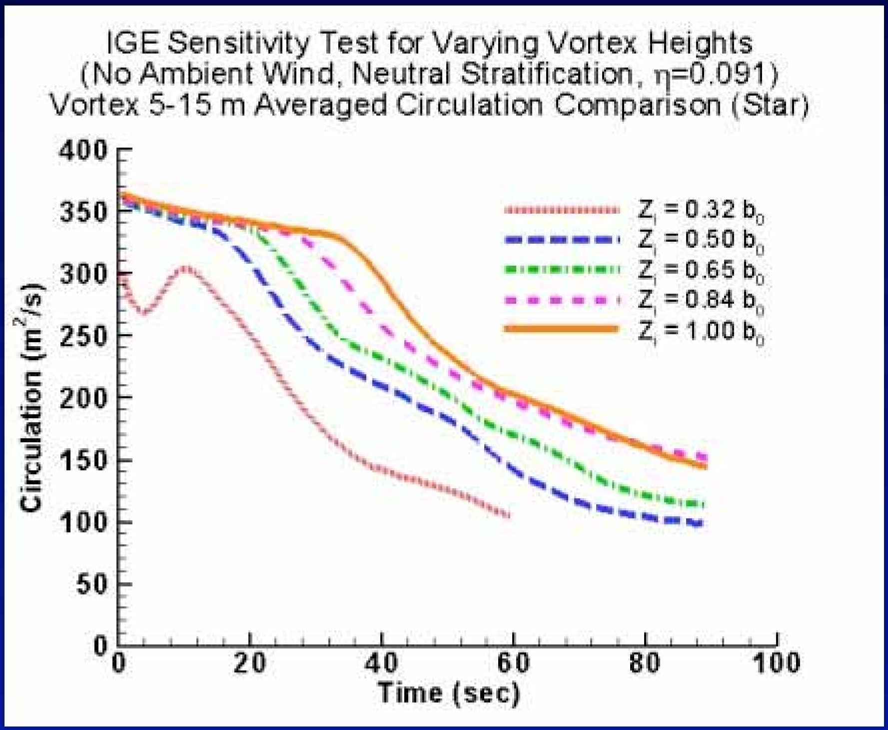
$$\frac{d\overline{\Gamma}}{dT} = -F(T)\frac{\beta_2 + \beta_3 N^{*4}}{2} \operatorname{sech}^2\left[\left(\beta_2 + \beta_3 N^{*4}\right)\left(T - T_{ss}\right) - \alpha_2\right] - c_2\, Max\left\{\varepsilon^*, 0.08\right\}\overline{\Gamma}_D - A_2 Z\, N^{*2}$$

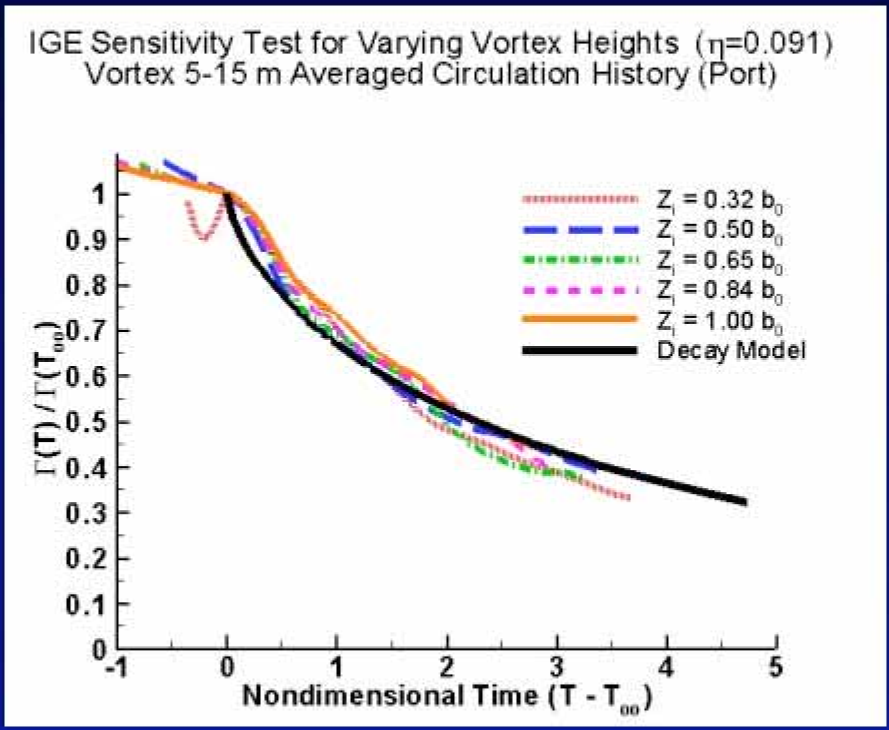
- Realtime wake prediction model for transport and decay out of ground effect
- Semi-empirical model with separate equations for vortex transport and decay
- Developed from TASS parametric simulations
- Validated with field measurements

Ground Linking



3-D TASS Circulation Decay: Ground Effect Normalizations





IGE Decay

Simple Relationships Derived by Fitting TASS data

$$\frac{\Gamma}{\Gamma_{oo}} = \mathrm{Exp}\{\frac{-2(T - T_{oo})^{2/3}}{5}\}$$

$$\frac{d\Gamma}{dT} = -\frac{4\Gamma}{15(T - T_{oo})^{1/3}}$$

where T is nondimensional time, T_G is the nondimensional time of maximum descent into ground effect and $T_{oo} = T_G + 0.25$ and Γ_{oo} is the circulation at time T_{oo}.

- **Relationship incorporated into APA V-3.2 realtime wake predictor**

Supporting yet another Aircraft Accident

- American Airlines Flight 587 crashed after takeoff at JFK on November 12, 2001 killing all 260 0n board plus 5 on the ground
- NASA was requested to support NTSB investigation and testify at October 30, 2002 public hearing
- NASA reconstructed wake vortex location and strength at the time of the accident using TASS (Terminal Area Simulation System) and the AVOSS Prediction Algorithm (APA)
- NASA analysis used "observed data" from
  - LLWAS sensors, ITWS, mesoscale weather prediction models, and National Weather Service observations
  - accident aircraft and previous aircraft flight data recorder
  - eyewitness accounts
- NASA's investigation revealed FL-587 may have encountered the wake vortex from a B-747
- Web Link to report: //techreports.larc.nasa.gov/ ltrs/PDF/2004/tm/NASA-2004-tm213018.pdf

Summary and Conclusions

- Development of TASS configured to support NASA programs
- TASS model is tool that is able to support aviation weather problems
- TASS can provide:
  - Understanding and characterization
  - Data sets for sensor evaluation and simulator studies
  - Guidance for predictive algorithm development
  - Support aircraft accident investigation
- TASS Model is a National Resource